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Development of a Novel Solution to Enable Integration and Interoperability for Cloud Manufacturing

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Abstract

Nowadays, manufacturing enterprises have been faced with a globalized competitive environment. In this fierce condition, Cloud Manufacturing paradigm emerged as a promising concept for competition. It provides effective solutions and tools for manufacturing enterprises to collaborate in globalized market. The revolution that Cloud Manufacturing has created is based on the redefinition of the classic methods to those which are appropriate for todays' modern and globalized manufacturing environments. In parallel with cloud-based revolution, the expansion of internet-based technologies has been started. These technologies previously have been applied in many fields and resulted in interoperability and integration among different technological solutions. This promotes this paper to fill the gap which of technologies in Cloud Manufacturing solutions as well and enabling integrated and interoperable communication among manufacturing clouds. This paper has focused on the idea of manufacturing cloud integration and interoperability. The paper has studied the dominant Cloud Manufacturing researches to find the opportunities for proposing a novel solution. This solution is capable to resolve the integration and interoperability consideration for different manufacturing clouds. The paper has applied the EDI X12 standards for insuring an integrated and standard data format for its contribution. An example in area of Supply Chain Management will be discussed to show the capabilities of the proposed solution.

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Keywords: Cloud Manufacturing; Cloud Integration and Interoperability; Electronic Data Interchange (EDI); Vendor Managed Inventory (VMI).

1. Introduction

Todays' manufacturing markets face with a globalized environment which is extremely borderless and highly fluctuated [1-3]. One of the promising solutions which effectively can handle such concerns in manufacturing industry is Cloud Manufacturing paradigm [4, 5]. Cloud Manufacturing is an idea based on Cloud Computing paradigm [6]. Cloud Manufacturing causes a great impact on industry and changed the way that enterprises fulfill their businesses [7]. Researches indicate cloud-based solutions as promising tools for today's globalized manufacturing environments [8, 9]. Of the most dominant characteristics of Cloud Manufacturing is known to be its service oriented approach which has created new opportunities for manufacturing enterprises to provide or acquire resources as service [10]. These providing and acquiring happen among manufacturing clouds. So, such interactions among manufacturing clouds need to be considered. A major reason which prioritizes these interactions is extreme growth of manufacturing clouds. As the number of manufacturing clouds increases, the need for integration and interoperability among manufacturing clouds intensifies.

On the other hand, there is a new trend in the application of Internet of Things (IoT) concept in industry sections, especially in cloud-based solutions [11]. Basically, IoT has been developed to create an internet-based environment [12]. Despite of preliminary expectations from IoT to connect everything to exchange information through internet, recent researches have discovered IoT as a key enabler for industrial purposes [13].

Considering the requirements for integration and interoperability for manufacturing clouds, the paper focuses on proposing a platform which supports manufacturing clouds' interactions in an integrated and interoperable manner. In this platform, IoT will be introduced as a bed which causes

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heterogeneous manufacturing clouds components interact with each other by means of internet-based tools and its capabilities.

Proceeding the paper will review Cloud Manufacturing related researches in Section 2. The review will focus on the ideas which have applied Internet-based solutions for providing service oriented mechanisms in Cloud Manufacturing environments. Considering the gaps of the studied researches, the paper will propose a novel solution for enabling a Cloud Manufacturing platform to help integration and interoperability in Cloud Manufacturing environments in Section 3. Finally, a case study by focusing on Vendor Managed Inventory (VMI) concept has been considered by the application to clarify the aspects of this contribution using the EDI X12.

2. Review of Related Researches

In this section, the paper has conducted a review on Cloud Manufacturing researches. The studied papers have been discussed from contribution aspects, IoT utilization point of view, and the environment that clouds operate. The summery of the review presented in Table 1.

Wang *et al.* [14] have developed function block-based integration mechanisms to integrate various types of manufacturing facilities. It considered a cloud-based manufacturing system to support ubiquitous manufacturing which provides a service pool for maintaining physical facilities in terms of manufacturing services. The proposed framework has established an integrated manufacturing environment to provide hardware, like robots, as a service. The paper also has provided a flexible architecture for a Cloud Manufacturing system which contributed to the application of Cloud Robotic paradigm.

Yu *et al.* [15] have applied a Cyber Physical System (CPS) to link informational aspects of a cloud to physical aspects of a Computer Integrated Manufacturing (CIM) system. The CPS includes collaborating computational elements which control physical elements of the CIM system and help to share its infrastructures in Cloud Manufacturing environment.

Chen *et al.* [16] have suggested Enterprise Resource Planning as a service and named it as CloudERP. The proposed CloudERP has a platform which provides ERP related software and hardware as a service. The paper also proposes a web-based solution for automating ERP service customization process and in this way has improved the serviceability of the ERP software and platform.

Stock *et al.* [17] have studied the basic requirement of Small to Medium Manufacturing Enterprises (SMMEs) and have followed the concept of a cloud-based architecture to insure the availability of SMMEs software in a Cloud Manufacturing environment. They have addressed some of relevant infrastructures for a manufacturing clouds such as security, equipment, IT management, workflow and operational issues to make a platform to facilitate collaboration in a cloud-based environment.

Huang *et al.* [18] have proposed a platform, named as SME-oriented Cloud Manufacturing Service Platform (SME-CMfgSP), which has considered key technologies for implementing a manufacturing cloud platform in details. The architecture of the platform classifies a manufacturing enterprise into the twelve layers. The architecture presents the structure of a SME to provide its resource as a service. The platform has used internet-based tools in the last layer (twelve layer) to connect to the other enterprise but has not encountered the integration and interoperability considerations.

The reviewed researches show there is a gap on the application of cloud-based solutions for enabling interoperability and integration in Cloud Manufacturing environments. According to prior studies on Cloud Manufacturing paradigm [19-21], there are some efforts to enhance manufacturing cloud communications and interactions to develop integration and interoperability among them. But they are still lack of a platform which considers the different

Researchers	Contribution	The role of the Internet	Multi-Cloud Environment Characteristics
Wang *et al.* 2016 [14]	Providing robots in the Ubiquitous Manufacturing environment with utilization of the function block-based integration mechanisms.	Proposes an architecture which supports providing Infrastructure as a Service over internet network.	The paper has a hybrid cloud perspective and integrates hybrid manufacturing clouds to provide Infrastructure as a Service, but does not consider a multi-cloud view to integrate different clouds of the environment.
Yu *et al.* 2015 [15]	Development of a Cyber Physical System (CPS) to share its hardware resource on Cloud Manufacturing environment.	The paper does not consider interaction aspects for CPSs and does not state that the CPSs environment is utilize from internet or not.	The paper highly contributed to distributed manufacturing concerns and providing CPS capabilities through Cloud Manufacturing but does not consider existence of different manufacturing clouds.
Chen *et al.* 2015 [16]	Proposes a platform for Enterprise Resource Planning (ERP) as a Service through Internet-based environments.	The paper provides a platform for ERP systems which serves ERP system via Internet and composes a web service for ERP providers and users.	The paper follows providing a serviceable ERP system over Internet-based clouds, but there is not considerations on integration and interoperability for CloudERPs.
Stock *et al.* 2014 [17]	Proposing a Cloud-based platform to facilitate providing manufacturing hardware as a service.	The platform developed for providing hardware as a service in a cloud environment and does not considerations for cloud connections.	The platform has not a multi-cloud view for providing its resource as a Service. It has developed a single cloud without any consideration on cloud interactions.
Huang *et al.* 2012 [18]	Developed a SME-oriented Cloud manufacturing service platform (SME-CMfgSP) for small and medium sized enterprises in Cloud manufacturing environment.	The platform utilizes Internet to connect manufacturing clouds and sharing their provided services.	The platform highly dedicated to the creation and implementation of a cloud for small and medium sized manufacturing enterprises and had not consideration in SME-CMfgSP for integration and interoperability of manufacturing clouds.

aspects of integration and interoperability for manufacturing clouds.

3. IoT-based Cloud Manufacturing Platform

The Cloud Manufacturing was proposed to form a service oriented environment which aims to accomplish Everything as a Service (XaaS) paradigm. This paradigm enhances the effectiveness and efficiency of platform, software and infrastructure utilization. However, to the best of our knowledge, the emergence of the Cloud Manufacturing paradigm lacks for solutions which consider the integration of different manufacturing clouds (service providers' cloud and service applicants' cloud). To elaborate it more, the paper focuses a higher level of service-based architecture in which the different cloud-based environments are enabled to interact with each other and serve for their full potential as in their own service oriented architecture.

The proposed platform has transition mechanisms which enable the interoperability between service-based manufacturing clouds. The idea behind this contribution lies on two major mechanisms: service decomposition mechanisms and service mapping mechanisms. These mechanisms apply the service oriented approach of Cloud Manufacturing paradigm to enable the definition and application of services for manufacturing operations. Both of the mechanisms are considered to work based on the internet. The service decomposition mechanisms can be applied by different manufacturing clouds around the globe to enable them for decomposing their own defined services based on generic services. Considering each manufacturing cloud defines its own service oriented structures, the service mapping mechanisms map the manufacturing cloud services to an EDI-based structure and vice versa from EDI-based structure to other manufacturing cloud service structures which fulfills the integration issue while maintaining the interoperability among clouds. These mechanisms are shown in Fig.1 and has been described in following sections to elaborate the proposed mechanisms.

3.1. Service Decomposition Mechanism

Considering Cloud Manufacturing paradigm, enterprises need a platform for an integrated and interoperable communication among their manufacturing clouds. The paper aims to define the enterprise's capabilities, platforms, and resources as acquirable services. These services have an interface which the interoperability of the enterprise's cloud will be achieved through it with other enterprises. As the trends for the application of Cloud Manufacturing structures grows among the enterprises, the diversity of the clouds and the related structures become further. Considering that each enterprise can have its own cloud service structures, this diversity will be an obstacle among the seamless interoperability of the clouds. Moreover, the integration issues for communication of service structures will be an inevitable problem. To overcome this issue, the paper proposes a service decomposition mechanism. This mechanism is proposed to decompose the service structures of each manufacturing enterprises, and composition of generic services. These generic services are usually common among all manufacturing enterprise service structures. The diversity of the Cloud Manufacturing services is usually due to the diversity of the composition methods for generic services to form a definite service. This idea will enable the first step for enabling the interoperability among enterprises' service structures. Consider two enterprises which use their cloud service structures for ordering their raw material inventory orders, in both enterprises acquiring the raw material inventory level is a common service and is essential to be embedded in setting the order service (generic service: obtaining a definite raw material inventory level) but in Enterprise 1, it can be applied in a pull oriented ordering service structure and in Enterprise 2, it can be considered in a push oriented ordering service structure. The service decomposition mechanisms are defined in a two direction style. The paper considers this mechanism to be able for both, to decompose a definite service to its generic services, and vice versa, to compose a set of definite generic services for forming a definite service This mechanism can be interpreted as a gate for a dispersed environment of clouds, and as a processor for interoperability of services among two different Cloud Manufacturing environments.

3.2. Service Mapping Mechanism

The second proposed mechanism in this paper tries to establish a base for integration of the Cloud Manufacturing service frameworks. This base should be standard, and meaningful for service translation among different manufacturing clouds. As the diversity of manufacturing clouds are high and every manufacturing cloud has its own composition style, there is a need for a reference which supports the mapping of the generic services and their composition method in both directions. The service mapping mechanism is proposed to enable the mapping of different manufacturing clouds service structures to the service reference model.

EDI equipped with standards to exchange data via any electronic devices [22, 23]. According to the proposed mechanism for cloud integration and interoperability, EDI X12 is used to enable the mapping for each of the generic services to a EDI-based format. This works as a standard gateway for supporting the communication of Everything as a Service.

As EDI X12 is developed to encompass the entire electronic data interchange processes, it has great capabilities for supporting the communication and interoperability among different Cloud Manufacturing solutions. Applying this EDI-based solution, an interoperable and integrated environment will be achieved for Cloud Manufacturing. Since EDI is capable to exert any electronic device for data exchange, and the Internet intended as an enabler for Cloud Manufacturing service interoperability. The EDI X12 is designed to be accessed via the IoT paradigm. The different manufacturing clouds use the IoT tools for communicating with service mapping mechanism through their cloud services. When two manufacturing clouds interact in the proposed framework, the service structures of Enterprise 1, go through the IoT tools and communicate with the service decomposition mechanism. This

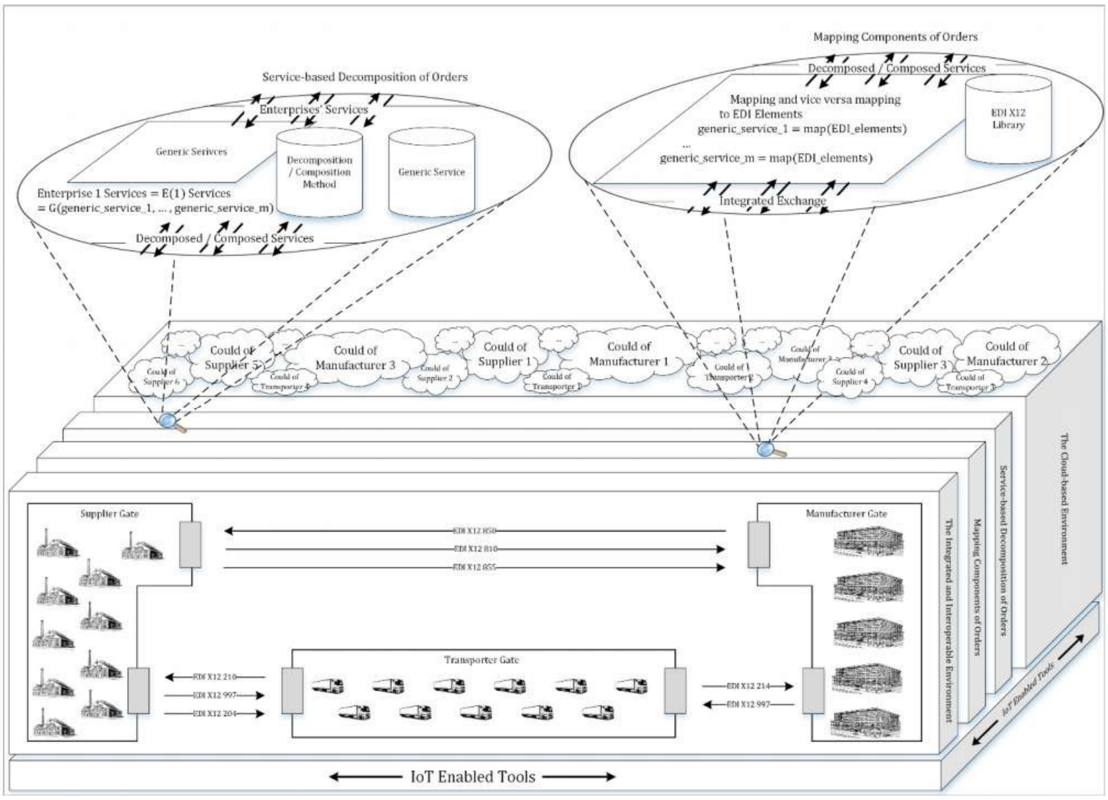

Fig. 1. Service decomposition and mapping layers help integration and interoperability among manufacturing clouds.

mechanism decomposes the Enterprise 1 services to generic services and then delivers them to the service mapping mechanism. This mechanism then maps the generic services to EDI X12 basic elements. Also, the methods of generic service composition are managed through the proper EDI X12 model. The service mapping mechanism then maps basic elements of EDI X12 to generic services and methods of composition, related to the second enterprise's service decomposition model. The service decomposition mechanism then composes the generic services based on the composition method and delivers it, via IoT tools, to the Enterprise 2 manufacturing cloud.

4. An Example

To indicate an application of the proposed platform, the paper considered an example which previously exerted over different industry environment. Vendor Managed Inventory (VMI) systems originally developed as an initiatives of Supply Chain Management to eliminate the destructive effects and results of self-managed supply chains. But the concept was more productive and improved different aspects of the industries [24, 25].

4.1. Vendor Managed Inventory (VMI)

Vendor Managed Inventory or VMI is a process where the vendors create orders information for their suppliers based on demand information that they receive from the customers. Such a system helps to reduce safety stocks. Therefore, decrease in inventory's level which can lead to cost savings. Lower inventory level, reduces the need for warehouse. Cost saving can also be found in reduced warehouse costs. This can enhance supply chain performance, decrease a lot of costs, reduce inventories, and eliminate devastating phenomena in supply chain such as bullwhip effect [26, 27].

As a VMI's final goal is to bring a close observation for supplier over the retailer sales and market condition, internet-based tools and standards have been found to be effective and essential solutions [28, 29]. As mentioned earlier about the IoT applications and EDI standards, these two insure a closer interoperability and integration between the suppliers and manufacturers. Moreover, as Cloud Manufacturing paradigm is getting more and more widespread, a novel idea can be offered to embed the service oriented paradigm in VMI systems. This will create a cloud-based VMI. The proposed cloud-based VMI is a simple example of a system among many different and dispersed clouds. So, by keeping this intention in mind, the next section will explain how to develop a VMI among clouds according to the proposed platform by means of EDI standards.

4.2. Integrated Cloud-based VMI

With VMI, the manufacturer specifies orders and sent to suppliers through the distribution channel using data obtained from EDI. There are a number of EDI transactions that can form the basis of the VMI process, X12 204, X12 210, X12 214, X12 810, X12 850, X12 855, and X12 997.

The first is the Purchase Order (PO), which is known as X12 850. The X12 850 is a PO transaction set, used to place an order for goods or services. The X12 850 generally provides the same information you would find in a paper PO document, including: item, prices and quantities ordered, shipping details, payment terms, and discounts.

After that the supplier receives order through the X12 850, it will be responded by X12 855 which is a transaction set for Purchase Order Acknowledgement. It is used by supplier to confirm the receipt of a purchase order (an X12 850 transaction) from a manufacturer, eliminating the need to call or fax for confirmation. The 855 also communicates whether the PO was accepted or rejected, or what changes may have been made to accepted orders. Thus, like many acknowledgement transactions, the 855 can indicate that the order was accepted, rejected or accepted with changes, as follows: accepted, rejected, or accepted with changes.

In parallel with this Purchase Order Acknowledgement a set of Invoice transaction are sent to the manufacturer as an EDI X12 810 which is sent in response to the X12 850 Purchase Order as a request for payment once the goods have shipped or services are provided. The supplier generates the X12 810 which commonly contains: invoice details such as invoice number and date, shipping details, payment terms, item information, and discounts.

After the reception has been done, the supplier sent an offer for a shipment to carrier cloud through an X12 204 which provides detailed information for carriers to deliver the order. This may include: carrier identification information, scheduling information, contact information for shipment recipient, description of goods shipping instructions, order information, product description, and physical characteristics.

When the carrier cloud received the advanced shipment notice, it uses X12 210 transaction set which is called the Motor Carrier Freight Details and Invoice. It replaces a paper invoice, used by carrier cloud to inform the supplier about the shipment performance and accomplishment. It provides an itemized detail including: invoice date and number, bill-to name and address information, order information detail, shipping methods and descriptions, consignee name and address information, terms of payment, and delivery information.

After the X12 210 is received, an X12 997 Functional Acknowledgment is sent back from the transportation provider to indicate that the X12 210 transaction has successfully received. The X12 997 is a transaction set known as Functional Acknowledgement which is sent as a response to X12 210 transactions received and shows the delivery, acceptance and rejection of the received transactions.

The carrier cloud provides the X12 214 transaction set which represents a Transportation Carrier Shipment Status Message and used to provide the status of the consignee's shipments. The X12 214 document may include: where shipped from, shipment location, dates and times for delivery, proof of delivery, and shipment status details.

As previous, an X12 997 Functional Acknowledgement will be sent in response to fulfillment of the shipment and order to the carrier cloud by manufacturer through their cloud.

5. Conclusion and Discussion

Nowadays, the competitive manufacturing environments have been faced with the globalization paradigm. Cloud Manufacturing has been known to be one of the dominant contributions in the area of manufacturing globalization. This paradigm has established an effective way for manufacturing enterprise collaboration in globalized environment. This paradigm introduces a service oriented concept and performs it by redefinition of manufacturing resources. This is a revolution that uses the redefinition of the classic methods of manufacturing to new definition that compatible with todays' business environments. However, to complete the collaboration, the communication of cloud services is inevitable. To complete this cloud-based revolution, the application of internet-based technologies has been widely concentrated. The new internet-based technologies as Internet of Things (IoT), Mobile Web, and recently Hypernet, are believed to strongly help the development and improvement of cloud-based manufacturing environments. However, there is still a considerable gap for a proper solution which consolidate the aforementioned technologies with Cloud Manufacturing solutions. This paper has focused on the concept of the IoT and has studied the dominant Cloud Manufacturing researches to propose contribution for a novel solution. This solution is not only capable to resolve the globalized Cloud Manufacturing fulfilment, but also it helps the integration and interoperability of different manufacturing clouds. The proposed idea supports both interoperability and integration among different manufacturing clouds by applying the EDI X12 standards as an integrated data format. This provides an integrated service management mechanism for clouds. The paper also has applied the EDI X12 standards for insuring integrated data formats. An example in the Supply Chain area has been presented. It exploits VMI concepts to elaborate the capabilities of the proposed solution. For further researches, the paper proposes the expansion of EDI X12 scope to other standards like ISO standard (especially ISO 10303) to cover a wider area of manufacturing operations.

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